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(54) Optical sensor.

(57) An optical sensor comprises a polychromatic light source (3), a detector (4), and first and second polarisers (7) (8) disposed in the light path between the source and the detector. The polarisation axis of the first polariser (7) is substantially orthogonal to that of the second (8), and there is a modulating element (6) of birefringent material disposed therebetween. The modulating element is disposed such that a change in the parameter to be measured alters the optical path length of the polychromatic light through the modulating element, thereby changing the colour of the light incident on the detector (4). The detector comprises first and second photo-responsive elements (9) (10), the responsivity with respect to wavelength of the first element (9) being different from that of the second (10). Signals from the photo-responsive elements are fed to a microprocessor (13) which calculates the colour of the light incident on the detector as represented by two or more parameters on the Chromaticity (CIE) Diagram, and interprets this colour in terms of the parameter to be measured.

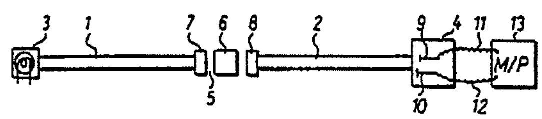

Fig 1

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OPTICAL SENSOR

This invention relates to the measurement of a parameter, and in particular to optical sensors utilising that property of some materials which is known as birefringence.

In a birefringent material the refractive index is not uniform for all directions, but varies from one direction to another. A beam of natural light entering a birefringent material will be split into two rays, the ordinary and extraordinary rays, one displaced laterally of the other. Each of the two rays is polarised in a different direction.

It is known to produce optical modulators employing birefringent materials. These known modulators, such as the Faraday effect modulator, vary the plane of polarisation of a beam of light in accordance with a modulating voltage or magnetic field applied to the birefringent material.

It is an object of the present invention to provide an optical sensor capable of measuring a parameter such as pressure, temperature, etc., employing a birefringent material.

Accordingly there is provided apparatus for measuring a parameter comprising a polychromatic light source; a detector, the source being adapted to propagate polychromatic light along a path to the detector; first and second polarisers longitudinally spaced one from the other in the said path and oriented such that the polarisation axis of the first polariser is substantially orthogonal to that of the second; a modulating element of birefringent material disposed in the path between the first and second polarisers such that a change in the parameter to be measured causes a change in the optical path length of the polychromatic light through the modulating element, and hence a change in the colour of the light incident on the detector, the detector comprising at least first and second photo-responsive elements, the responsivity with respect to wavelength of the first element being different from that of the second; and analysis means, signals from the photo-responsive element being fed to the analysis means which calculates, from the signals from the photo-responsive elements, the colour of the polychromatic light incident on the detector as represented by two or more parameters on the Chromaticity (CIE) Diagram, the analysis means being adapted to interpret the output of the detector in terms of the parameter to be measured.

The ordinary and extraordinary rays emerging from the birefringent modulating element will interfere destructively to suppress certain wavelength components of the polychromatic light. Thus the emerging light will have a 'colour signature' introduced by the birefringent material. The optical path length is the product of the refractive index of the material and the length of the path taken by the light through the material. A chance in either the refractive index or the length of the path through the material will cause a change in the wavelength components which are suppressed, and hence the colour of the light reaching the detector. For certain parameters, the parameter to be measured will directly affect the refractive index of the modulating element and vary the colour signature of the light emerging therefrom. For example, electric and magnetic fields will modify the refractive index of the element in this way. In addition, the refractive index of a lithium niobate modulating element will vary if a voltage is applied thereto. Other known birefringent materials can also be used in similar fashion.

In one convenient arrangement two different photo-responsive elements are employed, each with its own wavelength responsivity characteristic. Alternatively, one or both of the photo-responsive elements includes a coloured filter to impart a colour response characteristic, thereby allowing two identical photo-responsive elements to be employed, if desired. Preferably the responsivity with respect to wavelength of the at least first and second photo-responsive elements is such that their respective wavelength/intensity curves overlap for at least a part of the wavelength spectrum.

By employing at least first and second photo-responsive elements, a change of colour is determined by assessing the change in the whole of a selected part of the spectrum (colour modulation) as opposed to merely detecting the change at two or more selected wavelengths (wavelength modulation). Thus a change from colour A (represented by wavelength/intensity curve A) to colour B (represented by wavelength/intensity curve B) will be calculated from the area between the two curves, thereby giving a more complete analysis of 'true' colour. Wavelength modulation is less sophisticated in that it is a calculation based on the distance between the curves at two or more selected wavelengths.

By the term 'polychromatic light' there is herein meant any multi-wavelength radiation, and is specifically meant to include both visible light and infra red radiation. The term 'colour', whilst used herein for ease of understanding, should in no way imply that only visible light may be employed. Where the apparatus employs a source emitting radiation outside of the visible spectrum, the term 'colour' will refer to the spectral distribution of the radiation.

The modulating element is preferably disposed

such that a change in the parameter to be measured causes a movement of the modulating element in the said path. In one convenient arrangement a change in the parameter to be measured causes a change in the proportion of the modulating element which is in the said path. In an alternative arrangement the modulating element is disposed such that a change in the parameter to be measured causes a rotation of the modulating element about the longitudinal axis of the polychromatic light path. As in a birefringent material the refractive index is not uniform in all directions, any rotation of the modulating element will alter the refractive index of the material through which the light passes and hence the optical path length also. Alternatively the modulating element is disposed such that a change in the parameter to be measured causes a change in the length of the path taken by the polychromatic light through the modulating element. Any change in the total path length taken through the modulating element will also vary the optical path length, and hence the wavelength components which are suppressed by destructive interference, and therefore the colour signature of the light reaching the detector.

Conveniently the modulating element is non-spherical and is rotatably supported in the polychromatic light path such that a change in the parameter to be measured causes a rotation of the modulating element. Rotation of the element changes the thickness of the element though which the polychromatic light has to pass in order to reach the detector, and hence the colour signature of the light. Alternatively the modulating element is such that a change in the parameter to be measured causes a change in the dimensions of the modulating element. In one convenient arrangement the modulating element is secured in the polychromatic light path such that a change in the parameter to be measured causes a deformation of the modulating element. Where the parameter to be measured is a pressure, the modulating element is conveniently in the form of a diaphgram disposed in the polychromatic light path and arranged such as to be flexed by the pressure to be measured.

Alternatively where the parameter to be measured is a temperature, the modulating element conveniently comprises a thermally sensitive body disposed in the polychromatic light path such that a change in the temperature causes an expansion or contraction of the body. As before, the change in path length through the modulating element is responsible for a change in colour of the light which can be detected by the detector.

The invention further resides in a method of measuring a parameter employing apparatus as hereinbefore described. In particular, a method of measuring a parameter comprises the steps of providing a polychromatic light signal polarised at a first polarisation; passing said polychromatic light signal through a modulating element of birefringent material; disposing the modulating element such that a change in the parameter to be measured causes a change in the optical path length of the polychromatic light through the modulating element, and hence a change in the colour of the polychromatic light emerging from the modulating element at a second polarisation; detecting the intensity of the light emerging from the modulating element at the second polarisation with a detector comprising first and second photo-responsive elements, the responsivity with respect to wavelength of the first element being different from that of the second; calculating, from the output of the first and second photo-responsive elements, the colour of the polychromatic light incident on the detector as represented by two or more parameters on the Chromaticity (CIE) Diagram and interpreting the colour of the polychromatic light incident on the detector in terms of the parameter to be measured.

The invention will now be further described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of apparatus according to the invention;

Figure 2 is a schematic diagram of a modulating element according to an alternative embodiment of the invention;

Figure 3 is a schematic diagram of a modulating element according to another alternative embodiment of the invention; and

Figure 4 is a schematic diagram of a modulating element according to a further alternative embodiment of the invention.

Referring to Figure 1 there is shown a sensor comprising two aligned optical fibres 1 and 2 transmitting polychromatic light from a source 3 to a detector 4. An air gap 5 exists between the two aligned fibres 1 and 2, in which gap is provided a body 6 of birefringent material. A pair of crossed polarisers 7 and 8 are present in the air gap, one adjacent each of the fibres 1 and 2. Conceivably the polarisers 7 and 8 are attached, e.g. by a transparent adhesive, one to each of the optical fibres 1 and 2.

Polychromatic light, polarised by the polisarer 7, traverses the birefringent body 6 producing ordinary and extraordinary rays which interfere destructively at certain wavelengths. The resulting beam transmitted by the fibre 2 will therefore be polychromatic light with certain wavelengths components suppressed, thereby giving a distinctive colour to the light reaching the detector 4. A change in the parameter to be measured, such as for example temperature or magnetic field, alters the optical path length of the polychromatic light

passing through the body 6, causing different wavelength components to be suppressed, and hence a different colour signature to be imposed on the light reaching the detector 4.

The detector 4 comprises two photo-responsive elements 9 and 10, signals from which are passed via lines 11 and 12 to a microprocessor 13 for analysis. The microprocessor 13 calculates the colour of the detected light in terms of two parameters on the Chromaticity (CIE) Diagram from the signals from the photo-responsive elements 9 and 10. The microprocessor, on detecting a change in colour, may give an indication that a change in the parameter has been detected, for example on a display unit (not shown).

Figure 2 shows an alternative embodiment in which the parameter to be measured, for example pressure, movement, etc., is translated into a lateral displacement of the birefringent body 6 in the air gap 5. The body is mounted on a support 14, secured to a shaft 15 for movement caused by the parameter to be measured. Movement of the shaft 15 changes the proportion of the light which passes through the birefringent body 6 and hence the colour of the light transmitted by the fibre 2. The colour change is detected as described above and employed to give an indication of the parameter to be measured.

In the embodiment of Figure 3 the birefringent body 6 is rotatably mounted on a cradle 16. The parameter to be measured rotates the body 6 thereby changing the path length of the polychromatic light therethrough. As the suppression of wavelength components is caused by interference, any change in the path length will alter the wavelengths which will be suppressed. Thus the rotation of the body 6 causes a corresponding change in the colour of the light transmitted by the fibre 2, which is detected as previously described.

Figure 4 shows the birefringent body in the form of a diaphragm 17, secured between rigidly mounted supports 18 and 19. The parameter to be measured, in this case a pressure, causes a deformation of the diaphragm 17, varying the path length of the light therethrough. As previously described, this causes a change in colour of the light transmitted by the fibre 2, which can be detected to give an indication of the pressure causing the deformation of the diaphragm 17.

It will be appreciated that other arrangements can be envisaged to give a change in the path length of the light passing through a birefringent body. For example, the thermal expansion of a birefringent body can be employed to give a change in path length. A simple temperature sensor can easily be constructed in this way. Alternatively the body 6 can be arranged to be rotated about the axis of the fibres 1 and 2, thereby to alter the refractive index of the material presented to the light beam. It will also be understood that although only transmissive mode sensors have been illustrated herein, reflective mode alternatives could be easily constructed.

Claims

1. Apparatus for measuring a parameter comprising a polychromatic light source (3); a detector (4), the source (3) being adapted to propagate polychromatic light along a path to the detector (4); first and second polarisers (7) (8) longitudinally spaced one from the other in the said path and oriented such that the polarisation axis of the first polariser (7) is substantially orthogonal to that of the second (8); a modulating element (6) of birefringent material disposed in the path between the first and second polarisers (7) (8) such that a change in the parameter to be measured causes a change in the optical path length of the polychromatic light through the modulating element (6), and hence a change in the colour of the light incident on the detector (4), and analysis means (13), for interpreting the output of the detector (4) in terms of the parameter to be measured, characterised in that the detector (4) comprises at least first and second photo-responsive elements (9) (10), the responsivity with respect to wavelength of the first element (9) being different from that of the second (10), signals from the photo-responsive elements (9) (10) being fed to the analysis means (13) which calculates, from the signals from the photo-responsive elements (9) (10), the colour of the polychromatic light incident on the detector (4) as represented by two or more parameters on the Chromaticity (CIE) Diagram.

2. Apparatus according to Claim 1 characterised in that the modulating element (6) is disposed such that a change in the parameter to be measured causes a movement of the modulating element (6) in the said path.

3. Apparatus according to Claim 2 characterised in that the modulating element (6) is disposed such that a change in the parameter to be measured causes a change in the proportion of the modulation element (6) which is in the said path.

4. Apparatus according to Claim 2 characterised in that the modulating element (6) is disposed such that a change in the parameter to be measured causes a rotation of the modulating element (6) about the longitudinal axis of the polychromatic light path.

5. Apparatus according to Claim 2 characterised in that the modulating element (6) is disposed such that a change in the parameter to be mea-

sured causes a change in the length of the path taken by the polychromatic light through the modulating element (6).

6. Apparatus according to Claim 5 characterised in that the modulating element (6) is non-spherical and is rotatably supported in the polychromatic light path such that a change in the parameter to be measured causes a rotation of the modulation element (6).

7. Apparatus according to Claim 6 characterised in that the modulating element (6) is such that a change in the parameter to be measured causes a change in the dimensions of the modulating element (6).

8. Apparatus according to Claim 7 characterised in that the modulating element (6) is secured in the polychromatic light path such that a change in the parameter to be measured causes a deformation of the modulating element (6).

9. Apparatus according to Claim 8 characterised in that the parameter to be measured is a pressure, and the modulating element is in the form of a diaphragm (17) disposed in the polychromatic light path and arranged such as to be flexed by the pressure to be measured.

10. Apparatus according to Claim 7 characterised in that the parameter to be measured is temperature, and the modulating element (6) comprises a thermally sensitive body disposed in the polychromatic light path such that a change in the temperature causes an expansion or contraction of the body.

11. A method of measuring a parameter comprising the steps of providing a polychromatic light signal polarised at a first polarisation; passing said polychromatic light signal through a modulating element (6) of birefringent material; disposing the modulating element (6) such that a change in the parameter to be measured causes a change in the optical path length of the polychromatic light through the modulating element (6), and hence a change in the colour of the polychromatic light emerging from the modulating element at a second polarisation; characterised by the steps of detecting the intensity of the light emerging from the modulating element at the second polarisation with a detector (4) comprising first and second photoresponsive elements (9) (10), the responsivity with respect to wavelength of the first element (9) being different from that of the second (10); calculating, from the output of the first and second photoresponsive elements (9) (10), the colour of the emerging polychromatic light as represented by two or more parameters on the Chromaticity (CIE) Diagram, and interpreting the colour of the emerging polychromatic light in terms of the parameter to be measured.

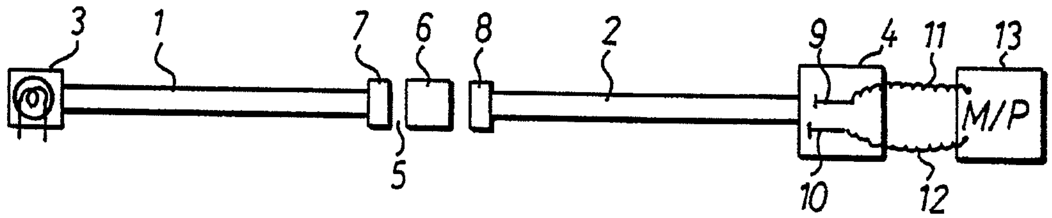

Fig 1

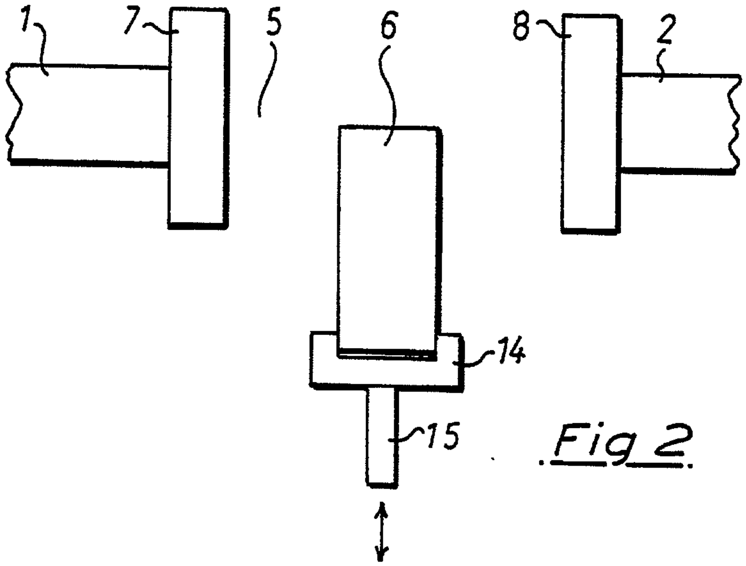

Fig 2

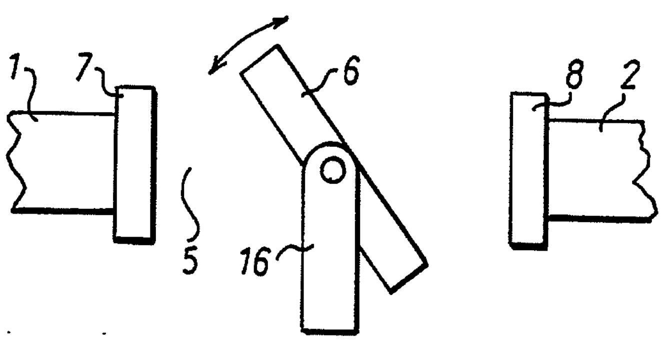

Fig 3

Fig 4